

## VERY HIGH TEMPERATURE CHEMISTRY

## Science Justification for Containerless Experimentation In Space

By

William H. Hofmeister, Vanderbilt University  
Paul Nordine, Containerless Processing, Inc.

Following is a summary justification for application of containerless processing in space to high temperature science. Low earth orbit offers a gravitational environment that allows samples to be positioned in an experimental apparatus by very small forces. Well controlled experiments become possible on reactive materials at high temperatures in a reasonably quiescent state and without container contamination. This provides an opportunity to advance the science of high temperature chemistry that can only be realized with a commitment by NASA to provide advanced facilities for in-space containerless study of materials at very high temperature.

The laws of thermodynamics provide a fundamental scientific motivation for efforts to advance high temperature science; heat engine efficiency increases with operating temperature. Consequently, the search for higher performance and fuel efficiency in automotive and gas turbine technology center on advances in high temperature materials. Experience also shows a connection between the useful and scientifically interesting properties of materials and their melting points. The hardest and strongest materials, superconductors with high transition temperatures, most semiconductors, refractory materials, high performance coatings and several excellent infrared optical materials melt at very high temperatures. The bronze, iron, steel, nuclear and silicon eras demonstrate that human progress is closely related to advances in high temperature materials technology. Finally, aerospace technology itself requires lighter, stronger, higher melting, and more oxidation-resistant materials. For these reasons it is important that opportunities to advance high temperature science be developed.

Thermodynamics also explains why containerless technology is needed in this effort. Solutions have larger entropies than their separated components, so the extent of container contamination of materials increases with temperature. Containerless processing in space converts this fact from a problem to a wide ranging opportunity for scientific progress.

## Examples

Comments on several selected areas of high temperature science are given below in which containerless processing in space has scientifically interesting and unique applications.

*Liquids* - An improved understanding of high temperature liquids is not only of scientific interest, but is also necessary to advance the art of high temperature processing. Novel experiments to measure the optical, thermal, mechanical, and other properties of liquids in containerless, space-based experiments would be feasible.

*Thermal properties* - Unusual variations of heat capacity with temperature have been determined for some liquid metals. Since the temperatures were measured by optical pyrometry with the assumption of temperature independent emissivity, it is possible that emissivity variations contribute to the apparent heat capacity effects. Continued Earth-based progress in this area is possible by making optical property measurements on electromagnetically (EM) levitated liquid metals. However, EM levitation is at best difficult,

complicated by stirring and sample oscillations, and applicable materials of high electrical conductivity. In space, measurements on a much wider range of liquids including poor conductors would be possible. Measurement precision would be advanced by the enhanced stability of melts positioned in microgravity.

*Phase relations* - Understanding the melting and solidification behavior of high temperature materials is essential to alloy and process design. Phase diagram determination by electromagnetic levitation techniques is well known. Acoustic positioning furnaces, with or without beam heating, will allow non-contact study of phase behavior to be extended to a wide range of materials. This is particularly important in complex systems that form many condensed phases such as the ceramic superconductor materials. The stability of any one phase in such systems is necessarily small relative to an equal composition mixture of other phases, and often sensitive to the impurities that result from processing in containers.

*Intrinsic properties of solids* - The synthesis of materials with improved homogeneity and purity, controlled chemical composition, and reduced mechanical flaws is needed to determine basic chemical-structural-property relationships. An improved understanding of optical and mechanical properties would have particular value to composite materials and fiber optic applications.

*Purification* - The environment in the wake of the shuttle or a wake shield can provide an extremely high vacuum unobtainable on earth. In addition, the effective pumping capacity of samples behind a shield is nearly infinite. This offers an opportunity to study the vacuum purification of materials at a level heretofore unachievable.

*Non-equilibrium materials* - Materials exhibit an increased solubility for their components at high temperatures, i.e., extended homogeneity ranges. Compositions of materials can thus be made that are retained as metastable materials when cooled to lower temperatures.

*Nucleation and undercooling* - The kinetics of nucleation processes provide another fundamental basis for interest in containerless processing. Solid containers induce heterogeneous nucleation from supersaturated or undercooled melts and also reduce the rate and uniformity with which melt cooling can be achieved. This greatly limits conditions under which homogeneous nucleation phenomena can be studied and non-equilibrium materials prepared. Supercooled liquids can be formed and their properties and process kinetics investigated. Some information has been obtained from studies of supercooled liquid metals by EM levitation and drop tubes. The versatility, control of cooling rate, applicability to poor electrical conductors, increased scale, ability to carry out repeated measurements on the same specimen, and other qualities that can be achieved by containerless experiments in space promise major advances in non-equilibrium materials.

*Novel processing techniques* - Certain processing techniques will benefit from the reduced gravity environment of space such as the manipulation of melts into useful shapes by aerodynamic, acoustic or electromagnetic forces. Conventional containerless processing could be applied to larger sizes and a wider range of materials. Indeed, the basic research expended in this area might yield as-yet unenvisioned processing opportunities.

## Conclusion

The laws of thermodynamics motivate efforts to advance high temperature science and explain why this is difficult in experiments that use containers. The low gravity environment of space allows versatile equipment for containerless experiments at very high temperatures to be developed. Much scientific and technological progress will be possible if such facilities are developed.